This book provides interesting reading material on some lesser known aspects of chemical elements of the New Age. Meant both for the layman and the scientist, the book discusses the elements and compounds found in the atmosphere and the earth's crust. While only unusual and technologically important properties of common elements are described, emphasis has been laid on applications of rare and man-made elements in superconductivity, computer and space research.

Dr D. V. Jahagirdar is professor of chemistry at the Marathwada University, Aurangabad where he has been teaching post-graduate students since the past thirty-five years. He was a post-doctoral Fellow at the Georgia State University, Atlanta (USA) during 1977-78 and at the University of Delaware, Newark (USA) during 1983-84. He has published three books, eighty research papers and regularly contributes popular science articles and stories to Marathi newspapers and journals.

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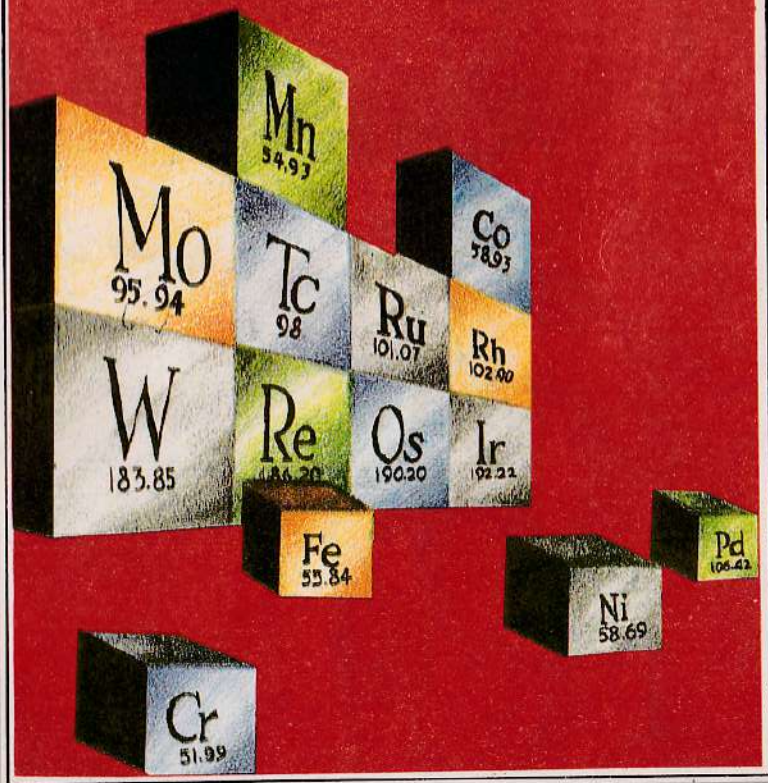
POPULAR SCIENCE

CHEMICAL ELEMENTS IN THE NEW AGE

D.V. JAHAGIRDAR



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Contents

Acknowledgement *vii*

Foreword *ix*

1. The World of Elements 1
2. Elements Atom by Atom 13
3. Common Chemical Elements 19
4. Rare Elements with Abundant Uses 37
5. The Radioactive Elements 53
6. Man-Made Elements 58

Acknowledgement

My sincere thanks are due to Dr R.A. Mashelkar, Director, National Chemical Laboratory, Pune, for the stimulating foreword. The fact that he found time despite his very busy schedule to write the foreword shows his deep interest in the spread of scientific knowledge. Dr Mashelkar states that the ultimate truth of scientific research and development, that the scientist's honesty and humility, and that his dedication and devotion have helped in discovering the novel applications of chemical elements of the New Age in our life.

My thanks are due to Ms Manju Gupta, Assistant Editor, National Book Trust, for her cooperation throughout the progress of the manuscript.

निदेशक
र.अ. माशेलकर

Director
R. A. Mashelkar

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PUNE 411 008.

Foreword

The present book is all about chemical elements and the vital role they play in our lives. It is such a great pleasure to write the Foreword for such a wonderful and creative work.

If science has to reach the common man, then it is essential that scientific thinking is conveyed in the simplest possible way by various communication means. The present contribution fulfils this task admirably.

There are several features of the book, which I was very impressed with. First is the very easy and lucid style in which the author writes. A complex subject like this can be understood even by the layman if it is written in such a simple style. Secondly, the book has several examples from real life, which helps one to relate to one's life. Thirdly, a wonderful historical perspective is provided in many cases. After all, isn't our present built on the efforts of scientists of the past, who have dedicated their lives to scientific pursuits? It makes me feel proud that I am a scientist. I also felt humble, since the toil that we scientists put in today is probably nothing compared to what our predecessors had put in. Such inspiring examples help us to re-dedicate ourselves to the cause of science with even greater vigour.

It is these and other such qualities of the book, apart from the essential information that it provides, which makes it a valuable contribution. I am sure the book will be extremely well received by a large community of students,

teachers, the common man and even senior scientists. I must congratulate Dr Jahagirdar very warmly indeed for such an outstanding piece of work.

R.A. MASHELKAR

1

THE WORLD OF ELEMENTS

We see a variety of materials and objects around us. In our house we have tables, chairs, buckets, cooking pots, kettles, water, plants, and so on. What are these objects made of? A table is made of wood, a bucket of plastic, a kettle of aluminium, cooking pots of stainless steel, clothes of cotton, to cite only a few cases (Fig. 1). In the sky above we see the sun, the moon, the planets and the stars (Fig. 2). All these objects on earth or in the sky are made of what scientists call matter. If we carefully analyse the objects that we see, we will find that they are different forms of matter which occupy space and have mass. Objects generally exist in three states, viz. solid, liquid and gas. Ice, water and vapour are simple examples of these states.

If we list some 50 objects and separate them on the

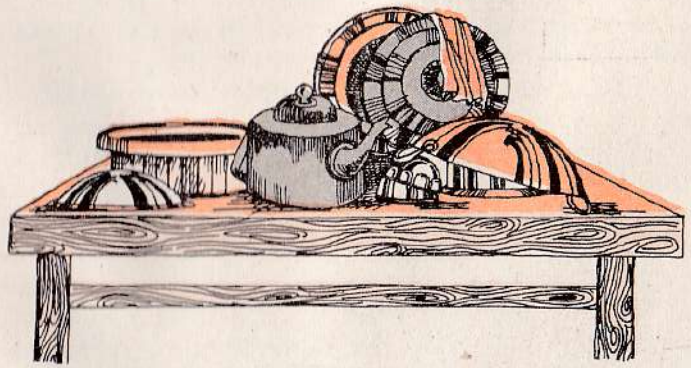


Fig. 1 : Objects made of different materials seen in a house.

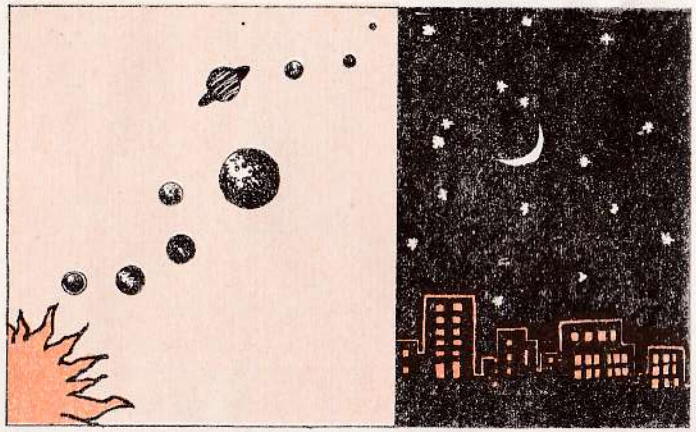


Fig. 2 : In the sky we see the moon, the stars, the planets.

basis of their state, whether they are living or non-living, visible or invisible, transparent or opaque, we find that some objects are solids, some liquids, and still others are gases. We have no difficulty in recognising certain forms of matter. We can see and touch solids like wood, iron or marble, and liquids like water, milk or petrol. But it is not easy to identify gases as matter because many gases are invisible, and we cannot really 'touch' them (Fig. 3). Yet, if we blow our breath against the palm of our hand, we can feel the onrush of gases contained in our lungs.

Sometimes we find that the substance we consider to be pure is in fact not so pure as we had imagined. Sea-water on evaporation leaves behind salts including sodium chloride. Now if an electric current is passed through molten sodium chloride, the salt breaks up into the metal sodium and a gas called chlorine. This breaking down of apparently simple substances into other substances can be continued till we reach the stage when we find that all matter is composed of only about one hundred 'pure' substances which cannot be broken down further into anything

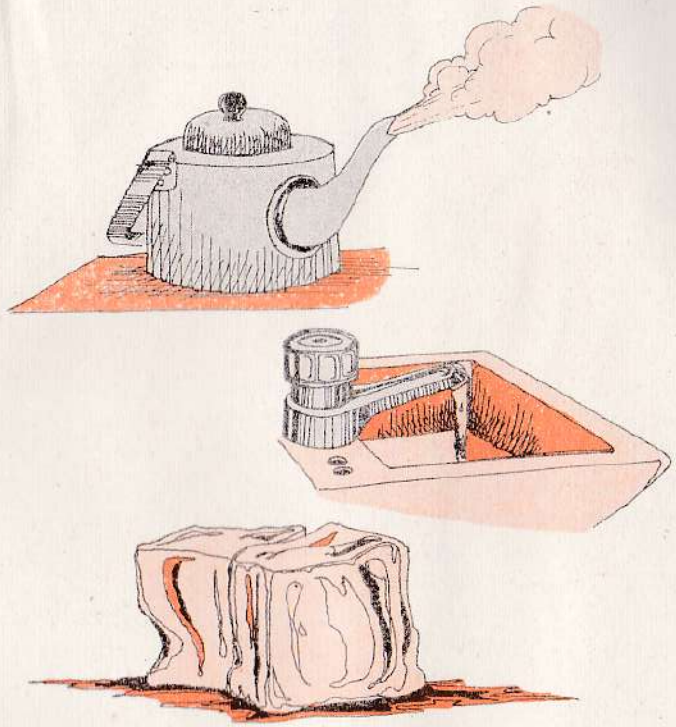


Fig. 3 : Water in the gaseous state, i.e. as steam; water as a liquid; water as a solid, i.e. ice.

simpler by ordinary methods of analysis. In other words, the objects we see around us are made up from only a handful of building blocks called *elements* (Fig. 4). The term normally indicates something fundamental, something simple with the aid of which more complex substances can be built up. Carbon, silicon, oxygen, iron, copper, silver, hydrogen are some of the common elements. Two or more elements can combine in a chemical reaction to form *compounds*. The materials we see are thus compounds of two or

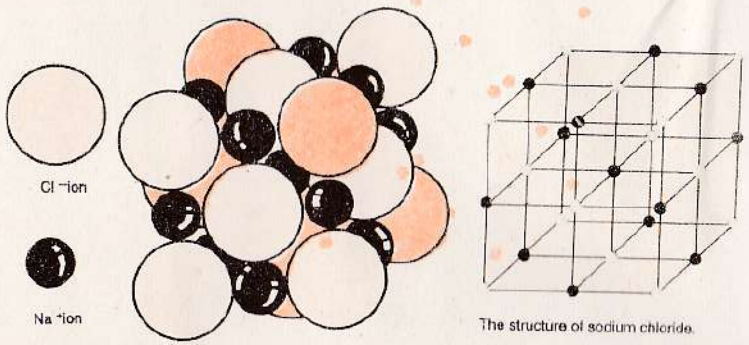


Fig. 4 : This arrangement of atoms and molecules makes up a repeating building block to produce a salt crystal.

more elements. Water is a compound of hydrogen and oxygen. On the other hand, neither hydrogen nor oxygen can be decomposed by the use of any form of energy (heat, light or electricity). Under ordinary conditions many of the elements are solids, such as gold, iron, copper and lead; others are liquids, such as bromine, mercury; still others are gases, such as oxygen, nitrogen and chlorine.

In ancient and medieval philosophy, however, the elements were thought to be in the form of four simple substances—earth, fire, air and water, of which the material bodies were supposed to be made. In pre-scientific chemistry, the elements were variously enumerated, the final number being five or six, such as spirit, salt, sulphur, water, and earth; or water, oil, air, salt and earth.

Using data obtained from his experimental studies of chemical reactions, the French chemist Antoine Lavoisier (Fig. 5) was able to prepare the first scientific list of elements, which he published in his renowned book *Traite Elementaire de Chime* (1789). He included in his list only 23 true elements as we know them today. Other entities in the list included substances which he called 'alkalis'—mainly oxides of certain metals, and surprisingly, also 'light and caloric', which have neither mass nor any of the other characteristics he had defined for elements.

Fig. 5 : Antoine Lavoisier.

The discovery of current electricity by Alessandro Volta (1800) provided an effective means for separating the more active elements from their compounds (Fig. 6). Soon thereafter, Sir Humphry Davy prepared the elements sodium and potassium by the electrolysis of their respective molten hydroxides, proving that the latter were compounds as Lavoisier had suspected. The formulation of the Periodic Law by Mendeleev in 1869 gave further stimulus to the search for new elements by indicating not only their existence but their probable properties as well. By the close of the nineteenth century the number of known elements had gone up to 82 and our idea of the nature and structure of matter was beginning to undergo changes. The number of elements known by the late 1950s was 102 of which 90 occurred in nature, either chemically free or in combination with other elements.

Of the approximately 90 naturally occurring elements, about 30 are found chemically free on earth; that is, not in chemical combination with any other element. These elements are obviously not very active chemically and include,

Fig. 6 : Alessandro Volta.

for example, nitrogen, gold, platinum, copper and the inert gases. However, oxygen, which is quite an active element, occurs in uncombined state in large quantities in the atmosphere and in combined form in water, rocks and minerals.

The word 'element' was first used in its modern sense by Robert Boyle (Fig. 7) around 1662 and it was clearly defined by Lavoisier in 1789 as the 'simplest form of matter'.

Elements are like alphabets and matter is like words. When alphabets are combined in different ways, different words are formed. Each word has a new meaning. Similarly, every compound produced by combination of elements has its own properties.

For every element there is an internationally agreed symbol that can be substituted for its name. The simplest symbol is the first letter of its name such as hydrogen (H), oxygen (O), nitrogen (N), and so on. There are many elements which have two-letter symbols, for example, calcium (Ca), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu) (from cuprum), lead (Pb) (from plumbum),

Fig. 7 : Robert Boyle.

Fig. 8.a : John Dalton.

sodium (Na) (from natrium), etc. (Fig. 8.b). The number of elements found in nature is much more than the letters of the alphabet and the total number of elements known today

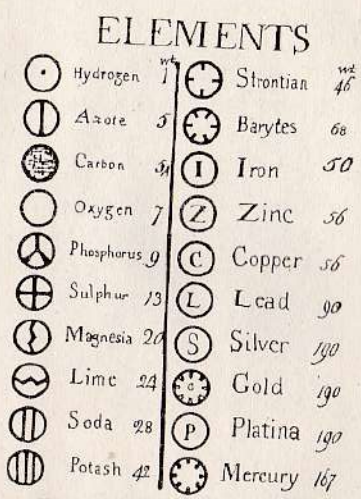


Fig. 8.b : Dalton's symbols for the elements.

is 109. Of these, about 90 occur in nature either chemically free or in combination with other elements. The rest have been produced artificially.

Origin of Elements in the Universe

The universe is composed of about 90-odd elements ranging from hydrogen to uranium. How did these elements come into being? We can get the answer to this question by studying the earth's crust, the atmosphere, the meteorites that have fallen on the earth from outer space, the stars, the galaxies and interstellar space. The most abundant element in the universe is hydrogen. It accounts for 93 per cent of the total number of atoms and 76 per cent of the mass of the known universe. Next comes helium which makes up 7 per cent by virtue of the number of atoms and 23 per cent by weight. All other elements beyond helium amount to only a little more than 1 per cent of the mass of the universe.

Several theories have been put forth to explain the origin of the chemical elements. Astronomers have

succeeded in identifying in the sun and other stars a great number of elements that we know on earth. They have not found any that are not known to exist on earth. Hundreds of meteorites have crashed through our atmosphere to land on earth. More than fifty of the elements known on earth have been identified in these bodies from outer space. One interesting finding is that the heavy elements took a long time to appear in the universe—probably one to two billion years. The oldest star in our galaxy is 6.5 billion-years old and the earth is 4.5 billion-years old.

Chemical Elements in the Earth's Crust

Most of the naturally occurring elements are found in the form of their compounds as minerals in the earth's crust. Very few are available in the elemental state. The earth's crust is like a thin skin with an average thickness of 40 km.

Elements	*Per Cent*
Oxygen	50
Silicon	23
Aluminium	8
Iron	5
Calcium	3.5
Sodium	2.7
Potassium	2.5
Magnesium	2.0
Phosphorus	1.2
All others	2.1

Eight elements make up almost 99 per cent of the earth's crust. Of these only oxygen is present extensively in the atmosphere in its elemental form, and only iron is used chiefly in its elemental form (Fig. 9). There are several elements which are present in quantities less than 1 kg/tonne, and some of the well-known elements like iodine,

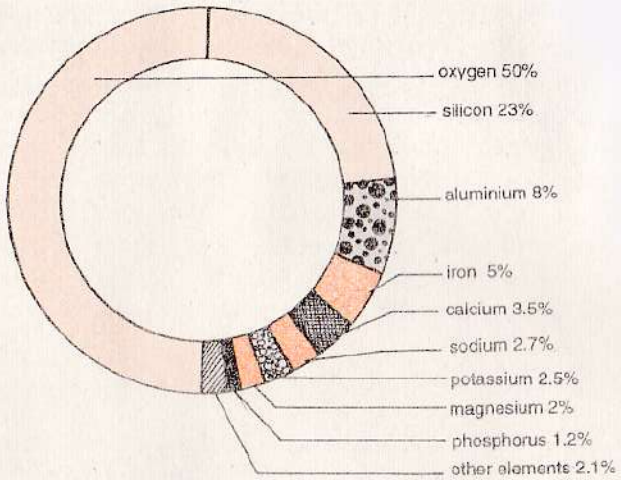


Fig. 9 : The proportion of the chemical elements in the earth's crust.

platinum and silver are found in quantities less than 0.3 gm/tonne. The precious metal gold is present in the earth's crust to the extent of only 0.005 gm/tonne and the rare gas elements are present to the extent of 0.001 gm/tonne. Among the most abundant eight elements, oxygen, aluminum and iron are the important ones used widely in industries. The abundance of the elements in the earth's crust, however, need not be taken as the popularity index of the elements. Rubidium is 16th in the order of prevalence, almost as abundant as chlorine, but its compounds are lesser known.

Elements which have long played an important role in our civilisation are often quite scarce. Gold is among the last few in abundance, yet its importance since time immemorial is well known. It is not the relative abundance but often the physical and chemical properties which decide the usefulness of an element. The generalisation is, however, not completely true in today's world. An element may be rare and difficult to isolate or synthesise (as in the case of the radioactive elements) in the pure state, yet scientists

Fig. 10 : Alchemists at work in their laboratory.

make all efforts to isolate and synthesise it if it has some unique, uncommon properties which are of interest to us.

Our understanding of the elements came through the works of alchemists (Fig. 10). Developments in mineral exploration and metallurgy during the last several centuries led to the discovery and production of new elements. Stupendous progress made in instrumentation and in theoretical physics during the beginning of this century led to the discovery of natural radioactivity. Transmutation of elements led to the production of artificial or 'man-made' elements. The total number of elements, available from natural as well as artificial sources, known at present stands at 109.

The rapid progress in technology since 1950 coupled with the fast-growing electronics industry introduced the need for a host of rare elements for a variety of purposes, like germanium and silicon for transistors, selenium for photoelectric cells and rectifiers, tungsten and beryllium for X-ray tubes and tellurium as a semi-conductor in

thermoelectric devices. The advent of computers and the Space Age led to a sea-change in man's approach towards understanding of metals.

After the start of nuclear energy programmes in various countries, new interest was created in some rare metals like gallium, indium and bismuth which serve as possible heat transfer media. Gadolinium, hafnium and boron, having high thermal neutron absorption cross-sections, were found useful as control rods in nuclear reactors; while plutonium turned out to be a good nuclear fuel.

New uses were found for known metals. Cobalt was in great demand because cobalt alloys were required in permanent magnets. Titanium with its high strength and low weight was found useful in aircraft and mining industries. Considerable progress has been made in this field during the last few decades.

Isolation of pure elements from their natural ores involves elaborate processes and economics of these processes finally determine their cost. To make them widely acceptable, their cost of production must be low. However, if the elements are of vital importance in defence or space research programmes then their cost of production is generally overlooked.

During the last twenty years, discovery of new methods of extraction and techniques of isolation have led to the recovery of elements which were otherwise scarce and difficult to convert into their elemental form.

2

ELEMENTS ATOM BY ATOM

The physical and chemical properties of the elements depend to a large extent on their atomic structure. All elements are made up of atoms. An atom consists of protons, neutrons and electrons. Protons and neutrons are present in the nucleus which is at the centre of the atom. Electrons are present in orbits around the nucleus (Fig. 11). A proton has one unit mass and one unit positive charge. A neutron has a mass which is almost equal to that of the proton, but no charge. The electron has a negligible mass but a unit negative charge. The mass of an atom is, therefore,

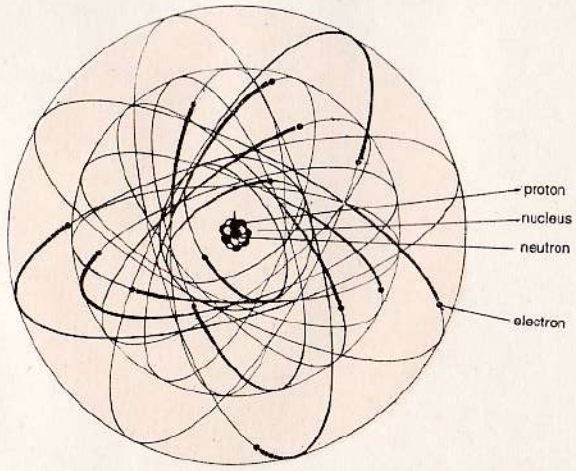


Fig. 11 : An atom consists of a nucleus which is made up of protons and neutrons and has tiny particles called electrons travelling around it in elliptical orbits.

concentrated in the nucleus. An atom is extremely small and cannot be seen even under a very powerful microscope.

The atoms of every element have a weight which is more or less fixed, depending upon the number of protons and neutrons in the nucleus. Atoms of the same element have the same number of protons, but the number of neutrons in their nucleus may differ. Since atoms are neutral, the total number of electrons in an atom is equal to the number of protons. The number of protons in an atom is called the *atomic number*.

The number of protons in an atomic nucleus identifies the element to which this atom belongs. For example, an atom of the element hydrogen has just one proton in the nucleus.

The number of neutrons in the nucleus of an atom of a particular element may vary, which gives rise to different isotopes of an element. Isotopes differ in mass number, which is the integral sum of protons and neutrons present in a nucleus. For example, hydrogen has two isotopes, deuterium and tritium with mass numbers 2 and 3 respectively (Fig. 12). Some isotopes, especially of the heavier elements, are radioactive and spontaneously emit α, β or γ rays from their nucleus. This phenomenon is known as natural radioactivity. Uranium is the most abundant naturally radioactive element.

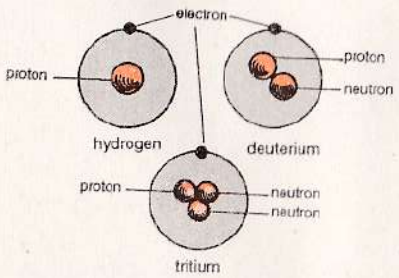


Fig. 12 : The hydrogen atom has two isotopes, deuterium and tritium with mass numbers 2 and 3.

Atoms combine to form molecules and in this process electrons in the outer shells are involved. The inert gases which have a unique electronic structure with complete valence shells are monatomic, that is, they exist as simple atoms and are represented as He, Ne, Ar, etc. Molecules of some of the common gases, such as hydrogen, oxygen and chlorine are diatomic and are represented as H_2, O_2, Cl_2, etc. In diamond, one of the crystalline forms of carbon, each atom is bound to four other atoms placed about it at the four corners of a regular tetrahedron (a solid formed by four equilateral triangles) and each of these in turn is similarly joined to four others, thus binding all the atoms in a crystal which may be regarded as a giant molecule.

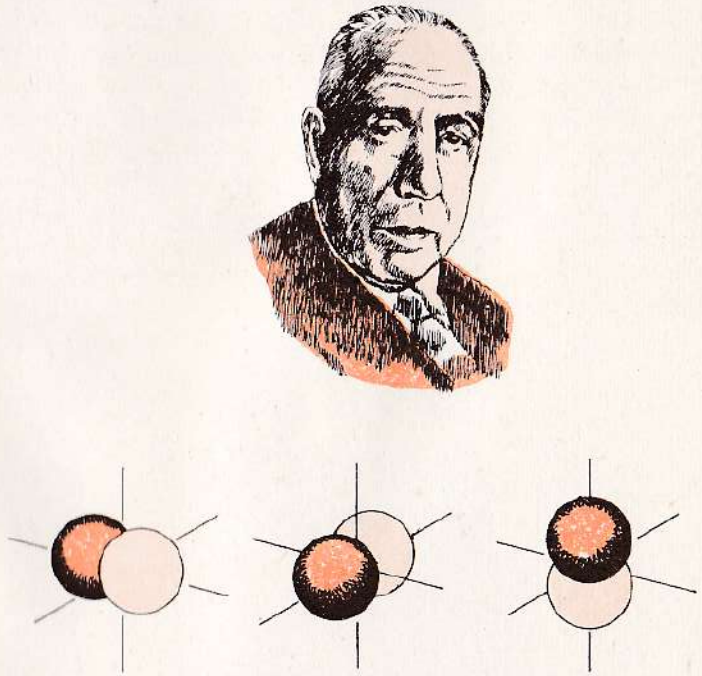


Fig. 13 : Niels Bohr (above); electrons in shells called orbitals around the nucleus (below).

Among the earliest scientists to propose a model of the atom was Niels Bohr (Fig. 13). In 1922 he proposed a model according to which electrons move around a nucleus in a fixed orbit. But Bohr's theory could not explain several experimental facts. Later developments in quantum theory led to the idea that electrons occupy concentric shells called *orbitals* around the nucleus where they are most likely to be found. These orbitals are divided into subshells of different shapes, combinations of which give rise to the chemical bonds.

The Periodic Table

During the eighteenth and nineteenth centuries, scientists gathered a lot of information about the different elements known at that time. They tried to find similarities amongst them. By 1850 sufficient information was available to classify these elements into some sort of groups. In 1869, the Russian chemist Dmitri I. Mendeleev proposed the Periodic Law, according to which chemical and physical properties of elements are periodic functions of their atomic weights (Fig. 14). The Periodic Table developed and perfected by

Fig. 14 : Dimtri I. Mendeleev.

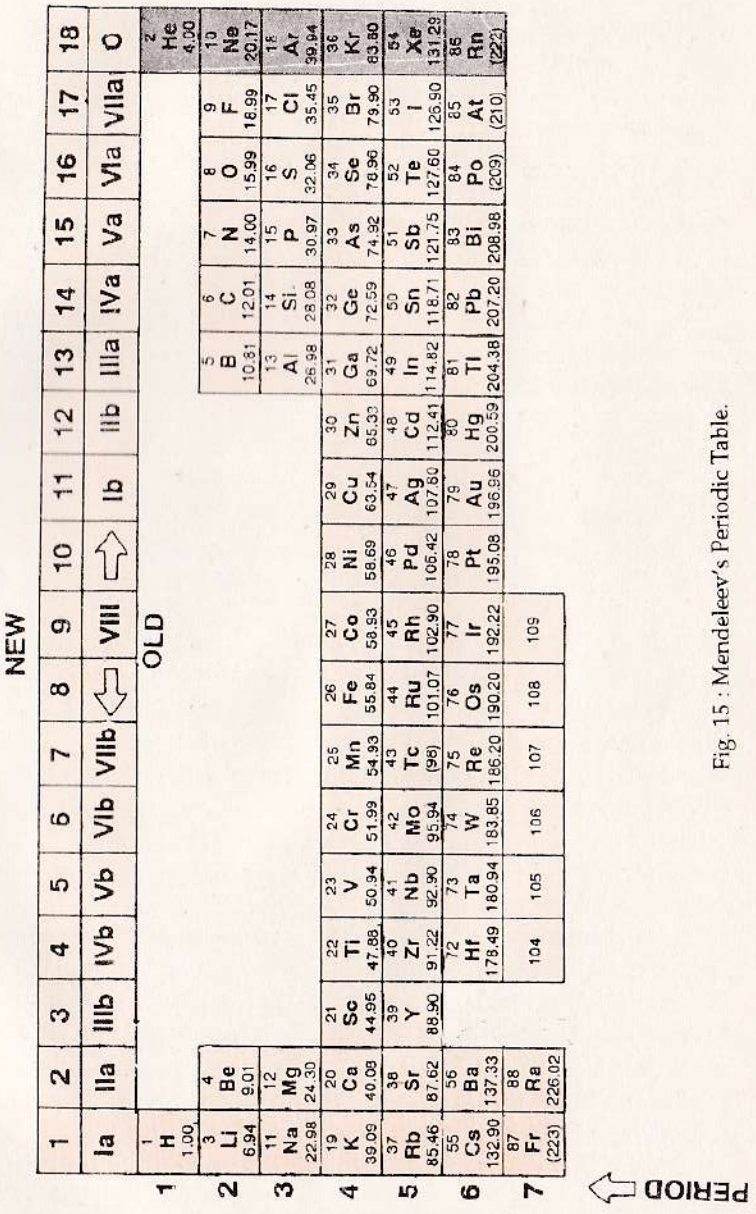


Fig. 15 : Mendeleev's Periodic Table.

Mendeleev was, however, based on an empirical correlation between the chemical properties of the elements and their atomic weights, whereas in reality they are related to the atomic numbers.

Mendeleev in his Periodic Table included not only the elements known at that time, but also had left some blank spaces for unknown elements. He had tremendous faith in the Periodic Law. On the basis of his Periodic Law, Mendeleev was even able to predict the properties of elements not discovered till then (Fig. 15). These elements were subsequently discovered and proved the validity of Mendeleev's Periodic Law. It was the discovery of the missing elements that finally led scientists to accept his basic scheme.

In the modern Periodic Table the chemical elements are arranged on the basis of their atomic numbers in seven horizontal periods with the lanthanons (lanthanum, 57 to lutetium, 71) and actinons (actinium, 89 to lawrencium, 103) arranged separately. The horizontal series of elements are called *periods* and vertical series as *groups*. The first period consists of two elements: hydrogen, (1) and helium, (2). Then there are two short periods of eight elements each: the first short period, from lithium, (3) to neon, (10) and the second short period from sodium, (11) to argon, (18). After this there are two periods of 18 elements each: the first long period from potassium, (19) to krypton, (36); and the second long period from rubidium, (37) to xenon, (54). Then follow very long periods of 32 elements, from caesium, (55) to radon, (86). In this period elements from lanthanum, (57) to lutetium, (71) are grouped together because they are closely related in their properties. These elements are called lanthanides or rare earth elements. The last period is incomplete. The properties of these elements indicate that this period is a very long period of 32 elements which would be completed at element 118.

3

COMMON CHEMICAL ELEMENTS

The forty-year period after the Second World War, which we may call the New Age, witnessed an unprecedented progress in the scientific field. Developments in rocketry, electronics, followed by the rapid progress in computer technology helped man to land on the moon. Computers, satellites, nuclear power, solar cells are areas in which many common elements are finding new uses. Many of these require metals with specific properties, which often involve isolation of rare elements in their purest form using new analytical techniques.

Common elements known to us since long have also contributed to the technological progress of the New Age. The physical and chemical properties of the first ten elements of the Periodic Table are well known. Many of them are today finding novel uses in space, energy and computer applications.

Hydrogen

The most abundant element in the universe is hydrogen. It accounts for 93 per cent of the total number of atoms and 76 per cent of matter in the universe. Hydrogen can be liquefied at -258°C for use as a propellant in powerful rockets, such as the Saturn V, which was used to launch the historic Apollo 11 mission to the moon (Plate I). These rockets are called cryogenic rockets because the propellants—liquid hydrogen and liquid oxygen—are stored at very low temperatures, of the order of -258°C.

Being the lightest gas, hydrogen was once used to fill balloons and dirigibles but because it is highly inflammable, it has been replaced by helium, the next lightest element. Today half of the hydrogen produced industrially is converted into ammonia which is subsequently used for manufacturing fertilisers and explosives. The gas is also used industrially in hydrogenation of vegetable oils for the production of *vanaspati*.

Since combustion of hydrogen produces nothing but pure water, it is also being touted as the fuel of the future. It can be conveniently used in fuel cells (Fig. 16) to generate electricity and produce water as a by-product. Such cells were used in the US Apollo missions to the moon (Plate II).

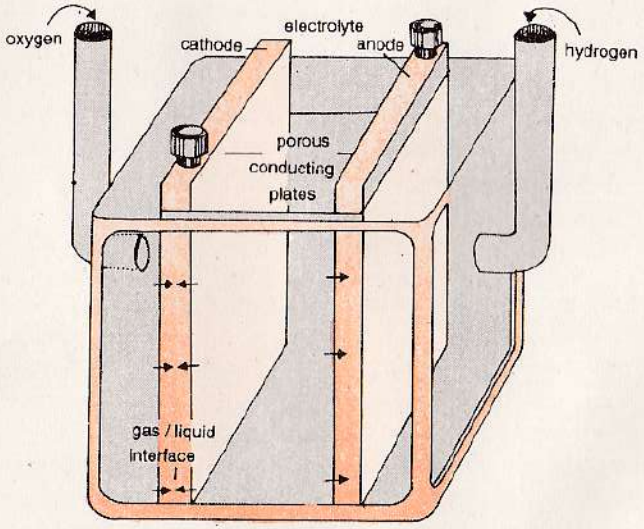


Fig. 16 : In this hydrogen-oxygen fuel cell, the gas reacts with the liquid electrolyte to form water and release electrical energy.

Helium

Helium is rare on earth though it is the second most

Fig. 17 : William Ramsay.

abundant element in the universe. Its presence was known on the sun from its spectral lines, twenty-seven years before it was discovered on earth. All stars are made of hydrogen and helium.

As early as 1903, William Ramsay, a chemist (Fig. 17), demonstrated that helium was a product of radioactive

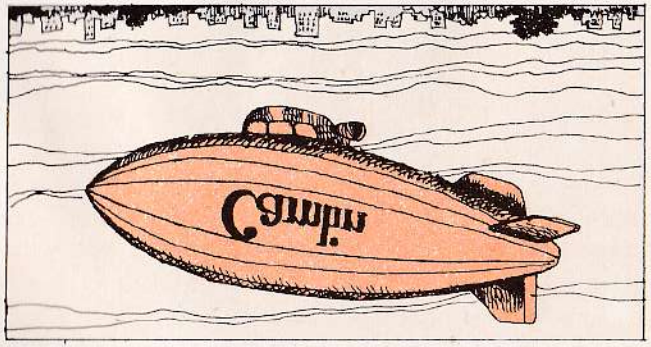


Fig. 18 : Helium is used in this blimp meant for advertisement purposes.

disintegration of radium. His experiment was an early example of the transmutation of one element into another. Since helium liquefies at a very low temperature (-269°C), liquid helium is widely used today in applications where extremely low temperatures are needed, such as in cryogenic devices. Being extremely light and non-inflammable, it is widely used in weather balloons and blimps (Fig. 18). Helium also finds use in electric-arc welding where it protects the metal from corroding while it is being welded.

Lithium

Lithium is the first member of the alkali metal family and is the lightest among metals. It is only one-fifth as heavy as aluminium and one-fifteenth as heavy as iron. It is much less abundant than sodium and potassium of the same family. A few decades ago lithium was not much in use. It was discovered in 1817 by the Swedish chemist A. Arvfedson who extracted it from the mineral petalite. Robert Bunsen (Fig. 19), the German chemist, isolated the pure metal by electrolysis of lithium fluoride in 1855.

Fig. 19 : Robert Bunsen.

Lithium is a highly reactive metal and difficult to store because it reacts violently with oxygen and nitrogen of the air. It is, therefore, kept embedded in vaseline or grease, which acts as a coating material, preventing it from coming into direct contact with air.

Lithium also reacts with hydrogen; in fact, it can absorb huge quantities of the gas. One kilogramme of lithium hydride, for example, can hold as much as 2,800 litres of hydrogen! During the Second World War, lithium hydride pellets were given to American pilots. If a plane crashed in the sea, the pellets would immediately react with water to liberate hydrogen to inflate life-jackets or rubber boats. In a way, the pellets acted like 'solid hydrogen gas'.

Lithium is the lightest metal known. Mixed with aluminium it produces an alloy which is 8 per cent lighter than other aluminium alloys. Such alloys are being used for advanced airliners with large carrying capacity and longer range.

Lithium salts of higher fatty acids—stearate or palmitate—are used as lubricants for machines, especially those meant for working at low temperatures in the Antarctic region. Lithium is also used in glass making. Lithium glasses have good stability to heat and are used in picture tubes of television sets. Lenses made of lithium fluoride single crystals enable astronomers to look further out into space as they allow ultraviolet radiations to pass through easily.

Because of its light weight and large energy associated with its oxidation, lithium has turned out to be an ideal material for batteries (Fig. 20). The all-solid state lithium-iodine batteries are now widely used in digital electronic devices which require low power. Such batteries can last as long as five years. If a little lithium hydroxide is added to the electrolyte of alkaline storage batteries, their service life is considerably increased.

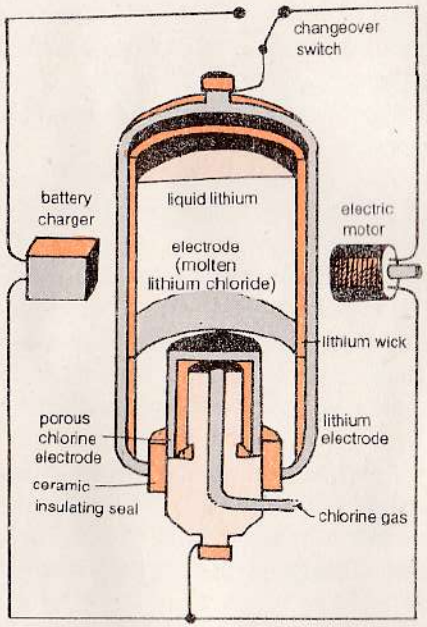


Fig. 20 : In the lithium-chloride battery, chlorine combines with lithium to produce lithium chloride and electrical energy. The cell can be recharged.

Beryllium

The world 'beryllium' comes from the mineral beryl. Big size crystals weighing hundreds of kilogrammes are present in the mineral. Beryllium resembles aluminium in many of its properties.

Discovered in 1828 by Fredrich Wohler and A. Bussy, the metal came into prominence with advances in technology. Its physical properties were found to be very interesting. It is a light metal, yet very strong; in fact, stronger than steel. Its melting point is higher than that of magnesium or aluminium. These two properties make it ideal as a metal for making aircraft bodies. It has an excellent thermal

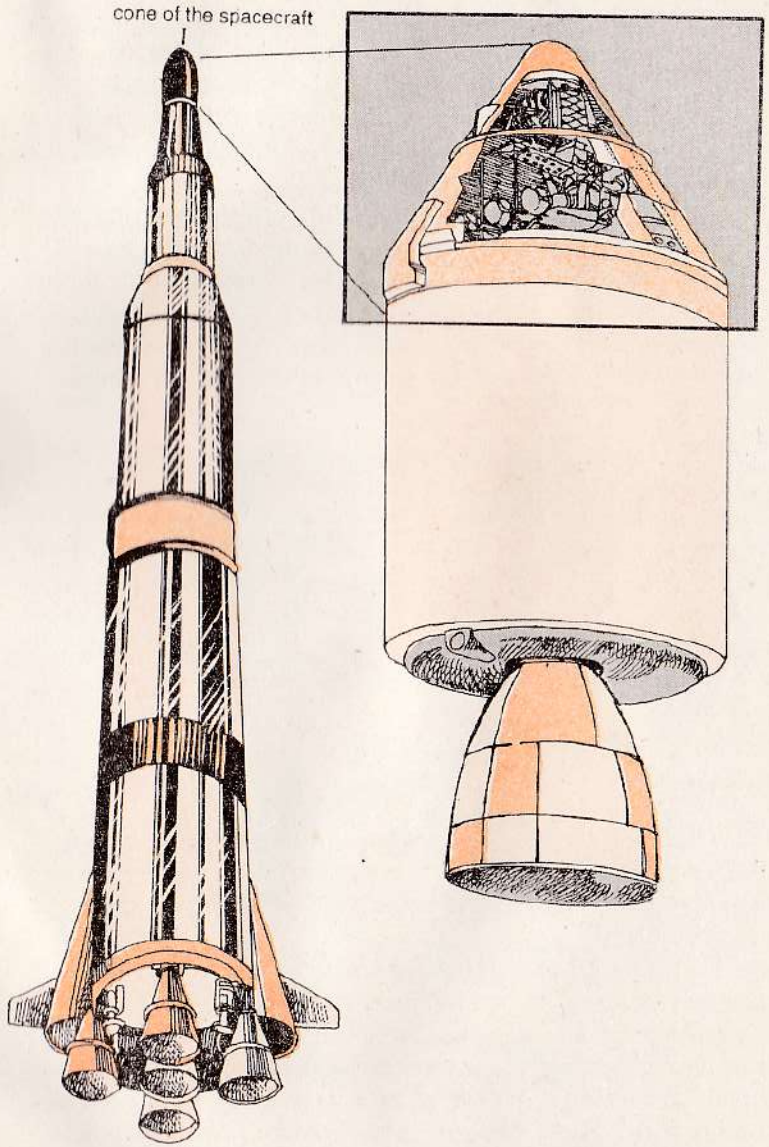


Fig. 21 : The cone of a spacecraft is made of beryllium.

conductivity and high heat capacity; hence, the crew cabins and cones of spacecraft (Fig. 21) are made of beryllium.

Another interesting property of beryllium is its capacity to release vast amounts of heat while burning. It thus has a potential for space-flights use as a rocket propellant, especially for flights to distant planets.

All metals show wear and tear and get fatigued like our muscles after hard work. Fatigued metals develop cracks and their efficiency decreases. Metals which have the tendency to develop fatigue cannot, therefore, be made to work efficiently under stress. Technologists are therefore always on the lookout for metals which do not develop

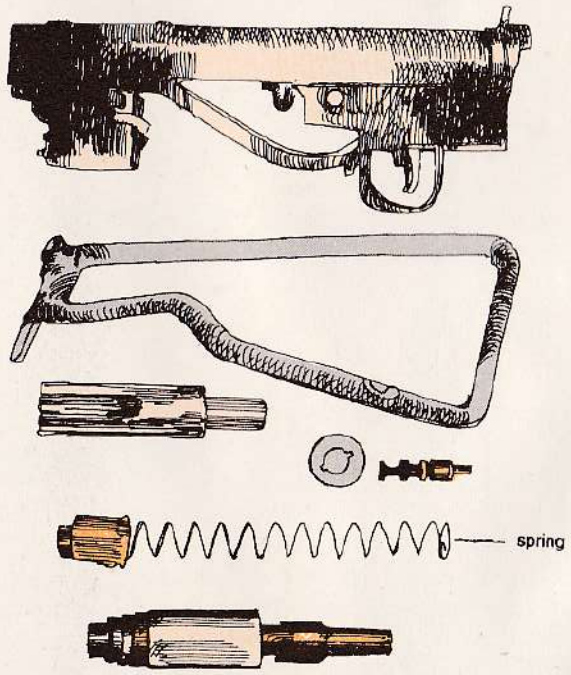


Fig. 22 : The spring used in a machine gun is made of steel containing beryllium.

fatigue and are light in weight. Beryllium fulfills their expectations.

When added to steel, beryllium can reduce the metal fatigue of steel to zero. Springs made of steel containing beryllium can withstand more than 10 million impacts without failure. Such springs are used in the latest models of rapid-firing aircraft machine guns (Fig. 22).

As beryllium allows X-rays to pass through better than any other metal, 'windows' of X-ray tubes are made of beryllium.

Boron

Boron is never found free is nature; it is always associated with oxygen. It is known in one form or the other, especially as borax, which means 'white'. Borax has been known for over 2,000 years and is used as a mild antiseptic and detergent. Elemental boron was first isolated by Sir Humphry Davy and, independently, by Gay-Lussac (Fig. 23) and Thenard in 1808. Pure boron is used for doping silicon for

Fig. 23 : Gay-Lussac.

making microelectronic devices. As it can absorb neutrons, pure boron is also used as control rods in nuclear reactors (Fig. 24). Boron fibres have low density yet high strength and find extensive use as reinforcement material in composites for use in aircraft and spacecraft. A compound of

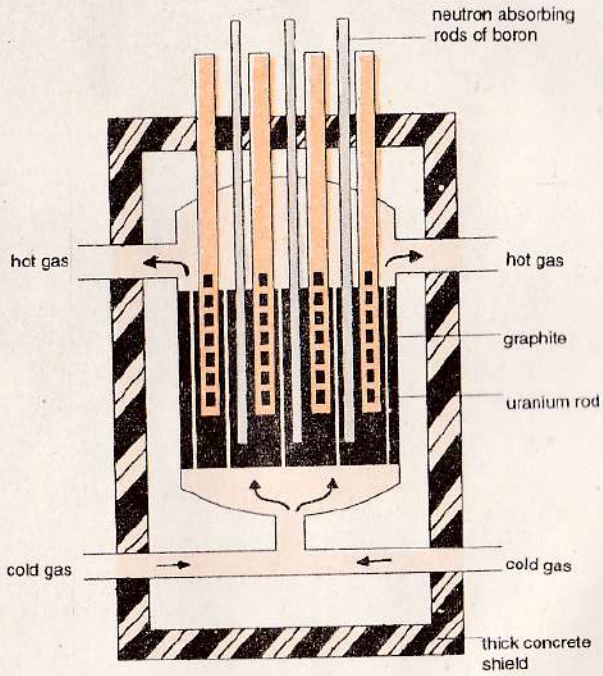


Fig. 24 : Pure boron is used as control rods in a nuclear reactor.

boron, boron nitride, is one of the hardest substances known. It is almost as hard as diamond and finds extensive use as an abrasive.

Carbon

Carbon is a unique element because of its capacity for

forming a large number of compounds. Most natural products—from plants and animals—fossil fuels such as coal, oil and gas, plastics and drugs, are some of the important carbon containing substances. Pure carbon is found in nature in three forms—as diamond, graphite and amorphous carbon. Of these, diamond is the hardest substance known while graphite it soft and is often used as a lubricant.

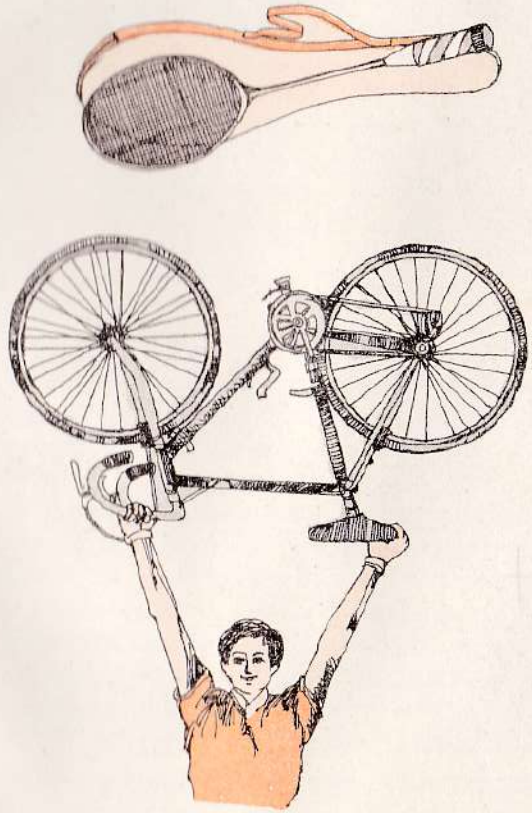


Fig. 25 : Carbon-fibre composites are used today in badminton rackets and bicycle frames.

Diamond is widely used in industrial cutting tools.

As a reinforcing material in composites, carbon fibres are much stronger and stiffer than glass fibres and are stable at high temperatures too. Carbon-fibre composites today find extensive use in applications where light weight and high strength are of paramount importance such as in aerospace parts; even tennis and badminton rackets and bicycle frames (Fig. 25)!

One of the hi-tech applications of carbon is in the form of artificial diamonds, which are used for making industrial cutting tools.

The radioactive isotope of carbon, C-14, forms the basis of dating archaeological artifacts. Known as *carbon dating*, this technique makes use of the constant rate of decay of C-14 in dead organisms such as wood or bones in which the concentration of C-14 decreases with time.

Nitrogen

This colourless and odourless gas makes up almost 80 per cent of air. It is extracted by first liquefying air and then subjecting it to fractional distillation. Having a boiling point (-195.88°C), lower than oxygen (-182.96°C), nitrogen boils off first. Industrially the most extensive use of nitrogen is made in the manufacture of chemical fertilisers.

Ammonia synthesised from nitrogen and hydrogen is used extensively in the fertiliser industry. TNT, a powerful explosive, is prepared by treating a coal tar product known as toluene with nitric acid. Liquid nitrogen finds extensive use as a refrigerant, and in cryogenic applications such as cryosurgery in which the extreme cold is used to destroy tumours or repair detached retinas (Fig. 26).

Oxygen

Oxygen is essential for human life and plants. It is the most abundant element on the earth. Like nitrogen, oxygen is

Plate I : Hydrogen was used as a propellant in the rocket to launch Apollo 11 in space.

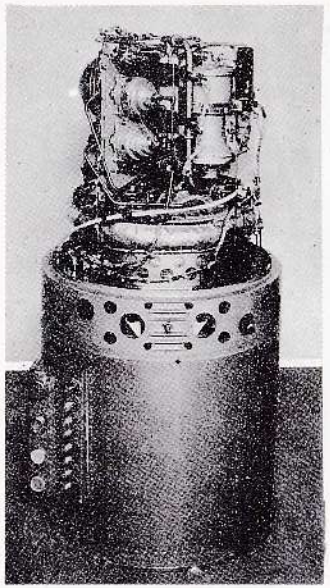


Plate II : This fuel cell with hydrogen and oxygen as its fuel was used in the Apollo spacecraft.

Plate III : Oxy-acetylene flame utilises oxygen when welding is done.

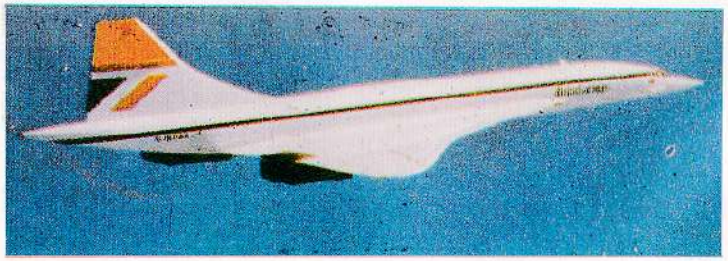


Plate IV : Aluminium is used nowadays in supersonic planes like the Concorde.

Plate V : Gold jewellery.

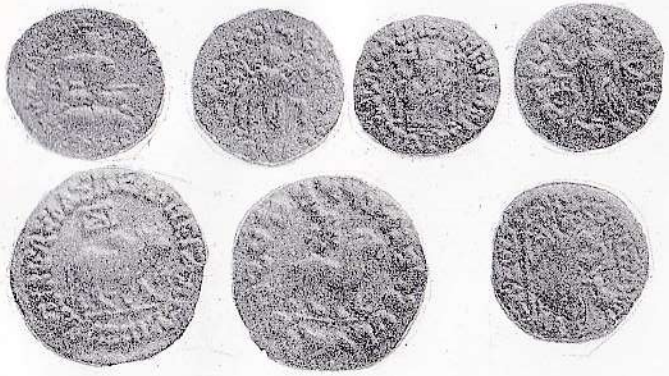
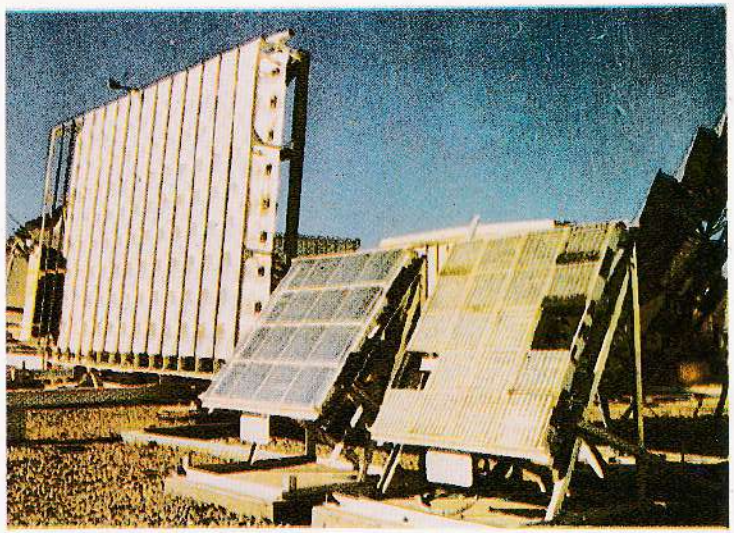


Plate VI : Copper coins.



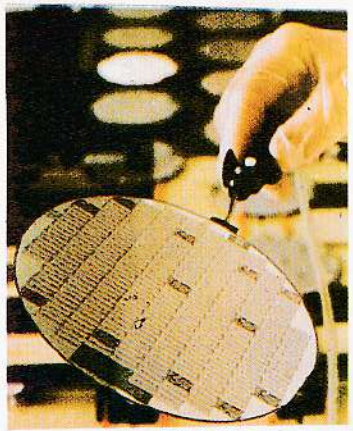


Plate VII : Solar cells and silicon chips.

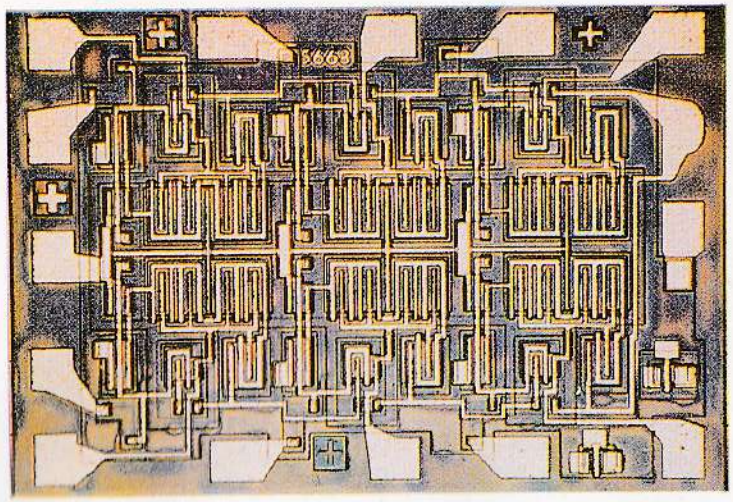


Plate VIII : Integrated circuit used in a computer.

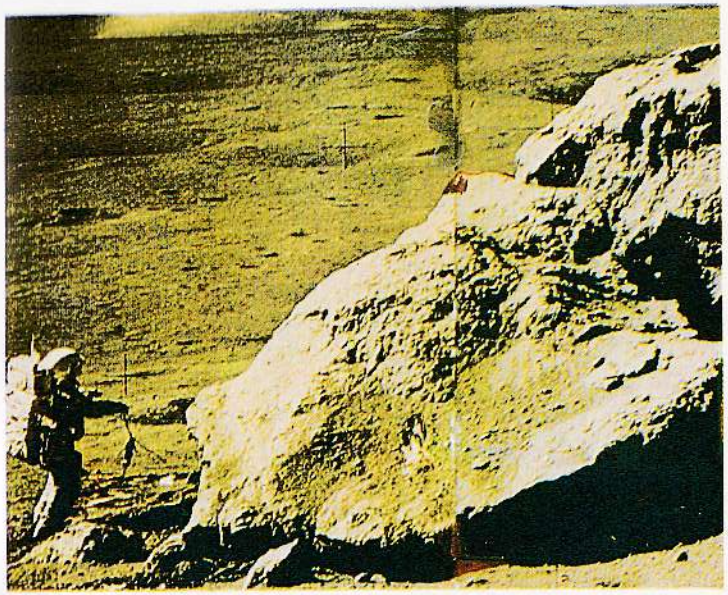


Plate IX : A part of the lunar rock which has been found to contain titanium oxide.

Plate X : Strontium is used in fireworks.

Plate XI : The nickel-cadmium storage cells can be recharged after use.

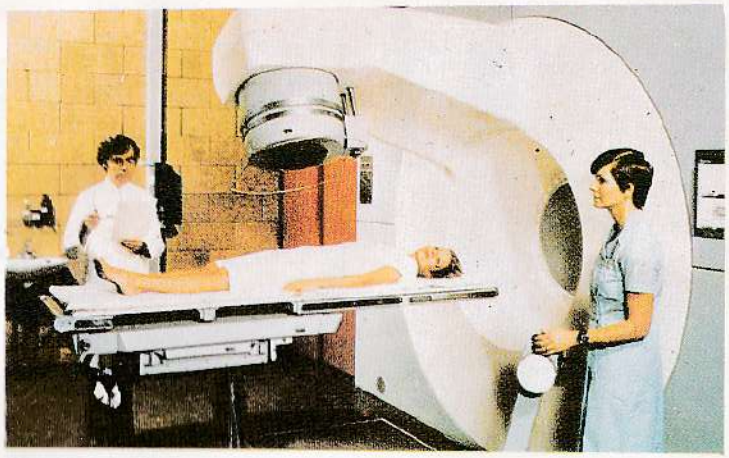


Plate XII : Radium is used in the medical treatment of cancer through radiography.

Plate XIII : Tremendous energy is released by this atom bomb.

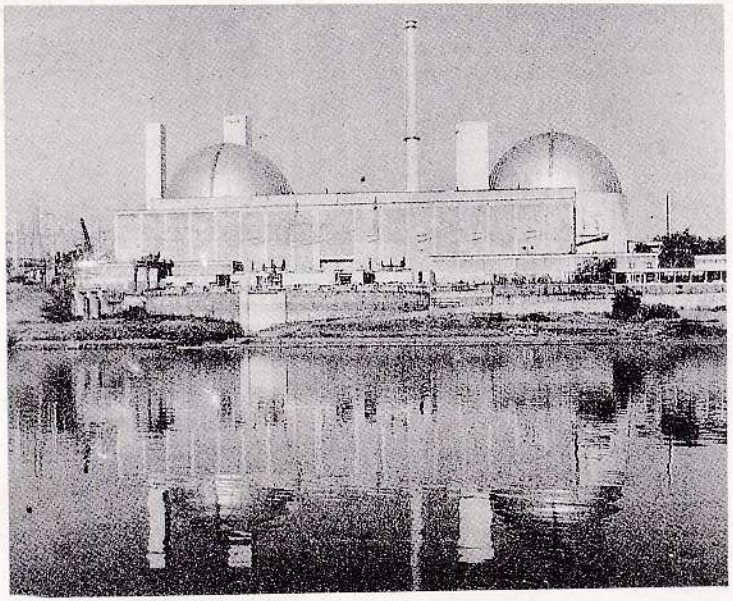


Plate XIV : A nuclear reactor uses uranium to generate electricity.

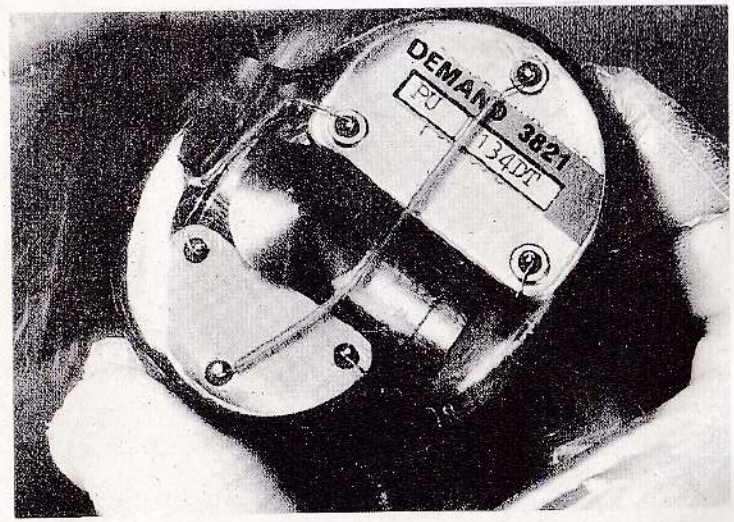


Plate XV : Plutonium battery is used in the heart pacemaker. It can last as long as twenty-five years.

Fig. 26 : Liquid nitrogen is used to repair detached retina.

also manufactured industrially by fractional distillation of liquid air. Pure oxygen is required in large quantities for industrial and medical uses. For example, one tonne of oxygen is needed to produce every 10 tonnes of steel from iron ore. Pure oxygen is also used in oxy-acetylene welding (Plate III) and cutting because of the extremely high temperature (3200°C) produced when acetylene burns in oxygen.

Liquid oxygen is used along with liquid hydrogen as propellants in cryogenic rocket engines which are powerful enough to launch geostationary satellites.

The common oxygen molecule contains two oxygen

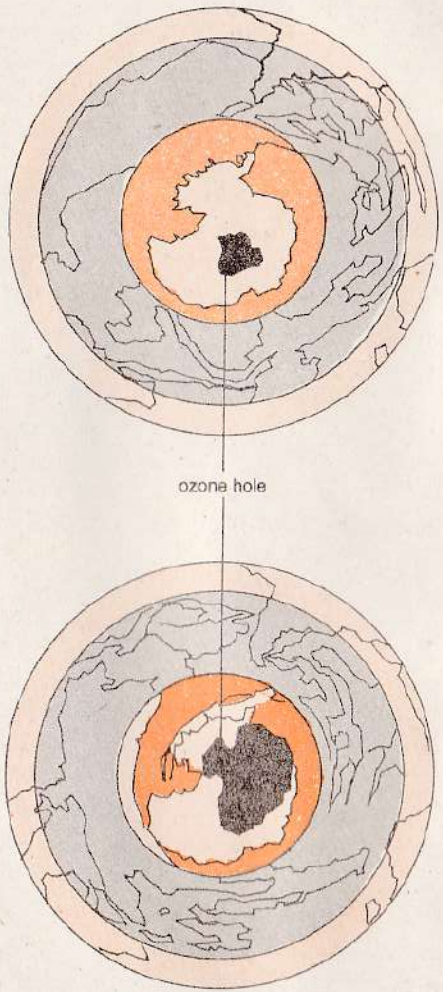


Fig. 27 : Chlorofluorocarbons react with ozone in the ozone layer to produce a hole in it. The illustration below shows the enlarged hole.

atoms. A molecule containing three oxygen atoms is known as ozone. It is produced by the action of ultraviolet rays on oxygen at heights of around 30 kilometres above the earth's surface where its concentration is the highest. This layer is called the ozone layer. It is considered vital for life on earth as it cuts off dangerous ultraviolet radiations from the sun and protects living beings from its harmful effects. The ozone layer blocks around 90 per cent of this radiation.

Of late, however, destruction of ozone in this layer has been reported, caused by the presence of certain industrial gases such as the chlorofluorocarbons in the upper atmosphere. These gases react with ozone in the layer, thereby reducing its concentration and producing holes in the layer (Fig. 27). These holes allow the harmful ultraviolet rays to pass through, posing risk to human life. Protection of the ozone layer is in fact a very important problem troubling the minds of scientists.

Fluorine

Fluorine is a highly reactive gas discovered in 1771 by Karl Scheele. It is the most reactive of all the chemical elements; virtually no inorganic or organic substance is immune to its attack. It is for this reason that the element is never found in the free state in nature. However, today it is one of the most important elements used in industry. Compounds of fluorine, especially some of its organic derivatives, are highly valuable industrial chemicals. The chloro-fluoro-carbons, or CFCs, are a group of highly stable, un-reactive chemicals used as cleaning solvents in electronics industry, refrigerants, aerosol propellants and foaming agents for polymers. Of late, however, the CFCs have come under attack from environmentalists in viewof their suspected role in the destruction of ozone in the upper atmosphere.

Teflon, or polytetrafluoroethylene, is a remarkable high-temperature polymer material which has exceptional

abrasion and corrosion resistance. It is widely used as a non-stick coating on kitchen utensils (Fig. 28) and as dry lubricant coatings on electric iron, and razor blades. Fluorine and its compounds also play a vital role in the production of uranium, especially enriched uranium, for use in nuclear weapons and power plants.

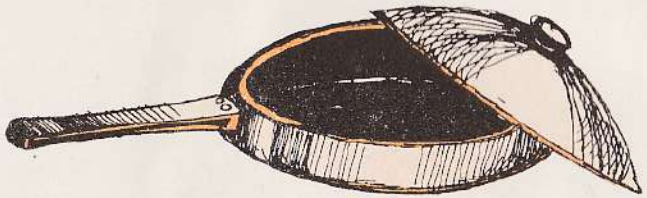


Fig. 28 : Teflon is a polymer used as a non-stick coating in frying pans.

More than 100 fluorochemicals of importance are known, with the promise of more to come from the most reactive elements in the Periodic Table.

Aluminium

Aluminium, because of its lightness, was among the first metals to be used in the manufacture of aircraft and missiles. Spaceships and satellites are made from aluminium alloys. It has replaced steel in the manufacture of submarines and supersonic planes (Plate IV). Aluminium foils as wrappers are being used extensively in every household in Europe and America.

Aluminium reacts readily with oxygen, violently at high temperatures. However, at room temperature a thin film of the oxide forms on the surface which protects it from oxygen. This film also protects aluminium from corrosion. This oxide film can be made thicker and tougher by a process called anodisation. Anodised aluminium resists corrosion much better and finds wide use in industry and also in homes in the form of cooking utensils, furniture,

door and window frames and the like.

Fabrics made with super-thin aluminium coating are finding interesting use, especially in cold countries. A raincoat made from this fabric can protect the user from both heat and cold. When the metal lining is outside, it protects the user from the heat of the sun. On reversing the coat, when aluminium lining faces inside, the user finds protection from the cold.

A remarkably new class of metals that would be coming into prominence in the near future are the foam metals. Aluminium foam is incredibly light and may find many more uses than the metal aluminium itself.

Copper, Silver and Gold

Copper, silver and gold have been known for more than five thousand years. Gold has been used in jewellery (Plate V) from historical times. Because it is very soft and malleable, it is alloyed with copper or silver to make jewellery. Pure gold is designated as 24-karat gold; 18-karat gold is three-fourths (18/24) of pure gold. Gold is the most malleable and ductile of all metals and is not affected by any chemical except *aqua regia* (a mixture of concentrated nitric acid and concentrated hydrochloric acid). The electrical contacts of microchips and many electronic gadgets such as music synthesisers, are coated with gold. It protects the contacts from corrosion and thus improves their reliability.

Silver too is soft and can be combined with other metals. Silver does not rust but develops a black coating on exposure to the atmosphere. The blackness is due to the formation of silver sulphide when the silver reacts with the sulphur containing gases present in the atmosphere.

Copper is a good conductor of electricity and is used in the form of conducting wires as it is much more cheaper than silver or gold. Copper wires are used in electrical equipments. Copper alloys are equally important—brass and bronze have been known to us for thousands of years.

Earlier, copper was used in the minting of coins (Plate VI).

Silicon

It occurs mainly as compounds combined with oxygen. Silicon in its purest form is a good semiconductor. A semiconductor is a substance which has a property between that of a good conductor (copper wire) and an insulator (glass, wood). The conducting power of a semiconductor can be regulated by doping it with other atoms. Pure silicon is used in making integrated circuits, solar cells and transistors (Plate VII).

In semiconductor devices single crystals of silicon are used. Controlled amounts of impurities are added during a process called 'doping' when producing single crystals.

As electronics developed, the size of the transistor also got smaller and smaller. In 1950, while only fifty transistors could be produced from 1 gm of the purest silicon, the number of transistors that could be produced from the same quantity shot up to 1,00,000 in 1980. This has been due to the development of integrated circuits. A single integrated circuit can hold as many as 10,000 transistors (Plate VIII).

4

RARE ELEMENTS WITH ABUNDANT USES

Titanium

Titanium is a common element that has been known for more than 150 years. It is the ninth most abundant element in the earth's crust—more plentiful than lead, copper and tin; only iron, aluminium and magnesium surpass it in abundance.

The element was first discovered in England by William Gregor in 1790, although in did not receive its name until the German chemist Martin Klaproth (Fig. 29) rediscovered it in Hungary in 1795 and named it after Titans, the mythological sons of the earth. The principal ores of

Fig. 29 : Martin H. Klaproth.

titanium are ilmenite and rutile. Klaproth and Gregor isolated it from rutile sand as titanium dioxide. Metallic titanium was first prepared by the American chemist Hunter in 1910. The metal was first produced commercially by E.J. du Pont and De Nemours and Co. (USA) in September 1946.

Pure titanium is a silvery metal which looks and behaves like stainless steel, but is only a little more than half as heavy. It will, however, never be as cheap as stainless steel because its refining and casting present difficulties.

Titanium rules as a supreme commander among the industrial metals. It has even replaced aluminium because it is six times stronger than the latter. It is twelve times harder than aluminium and four times harder than iron and copper. Its strength does not diminish even at high temperatures (500-600°C). The resistance to operational load is measured in industry by the term 'yield point', which gives a measure of the capacity of a metal to retain its shape and dimensions under stress. The yield point of titanium is 18 times higher than that of aluminium.

Since titanium is not affected by low temperatures, titanium tanks are used to store liquid oxygen in cryogenic rocket engines. These tanks can withstand temperatures upto -180°C.

The most important chemical property of titanium is its excellent corrosion resistance. Many of the strongest acids and alkalis, even when hot and concentrated, have no effect on titanium. Titanium pipes can be used to transfer strong acids and alkalis as they are unaffected by acids and alkalis even when used for several years. The metal shows amazing resistance to sea-water corrosion. No wonder, it is in great demand by the navy.

An alloy of titanium and nickel known as 'Nitinol' has a unique property of 'remembering' its shape. For example, if Nitinol wire is twisted into a spiral shape and then heated, and the hot wire is then dipped in ice water, the wire somehow 'memorises' its spiral shape. The Nitinol wire can now be straightened or given any other shape.

When the straightened or deformed wire is heated, it 'remembers' the shape it had been given and reverts back to the spiral shape again!

Titanium has a high electrical resistivity and is non-magnetic. If the electrical conductivity of silver is 100, then that of titanium is only 0.3. Titanium, therefore, finds use in electrical engineering. As demand for titanium increases, attempts are being made to get it from other sources apart from minerals found on earth. The examination of lunar rock has shown that it contains considerable quantities of titanium oxide (Plate IX).

Although at present it may sound crazy, the idea of bringing titanium from the moon may after all turn out to be practicable in future, because titanium is such a priceless metal—money spent on the project could never go waste!

Vanadium

Vanadium is a rare metal—the earth's crust contains something like 0.2 per cent. Ores containing 0.1 per cent of vanadium are said to be rich. Surprisingly, the meteorites that come down to the earth from outer space contain two to three times more vanadium than the earth's crust. Scientists are also trying to recover vanadium from marine animals. The concentration of vanadium in the blood of some marine animals has been found to be a billion times higher than that in sea-water. Marine animals like ascidians, and holothurians and sea urchins accumulate vanadium in their body from sea-water. Japanese metallurgists have produced steel in which vanadium obtained from ascidians has been used.

Why is this metal so important? Obviously it has some property not found in any other metal. True, added to steel even in very small quantities (fractions of a per cent), it can produce an alloy which is light and at the same time hard yet resilient. The alloy finds abundant use in the manufacture of automobile components (Fig. 30) such as engine

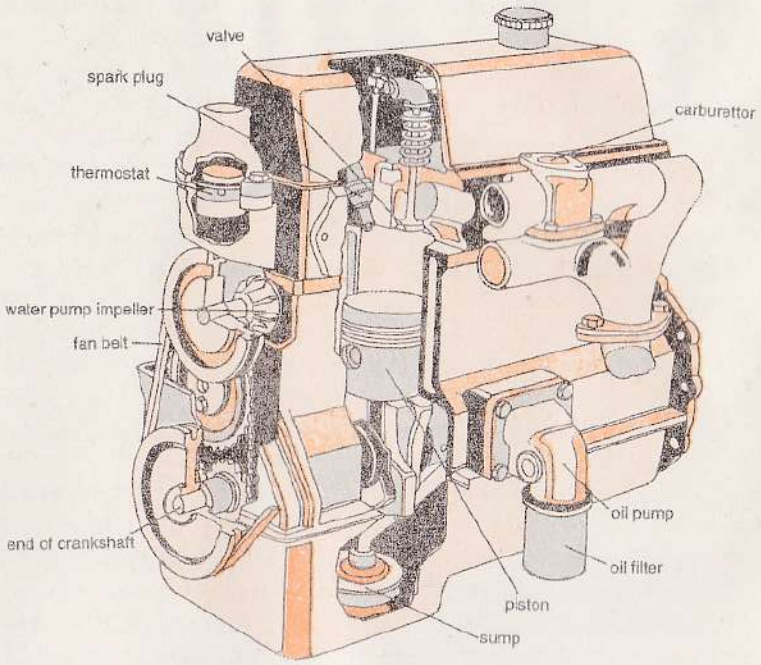


Fig. 30 : Vanadium is used in the manufacture of various parts of the automobile engine.

valves, axles, and springs. Almost pure vanadium was first obtained by the British chemist Henry Roscoe in 1869. It contained 4 per cent of impurities. The purest form, i.e. the metal with 99.99 per cent purity, can be obtained by electrolytic refining.

Vanadium pentoxide is used as a catalyst in the production of sulphuric acid. Vanadium salts, which are coloured green, yellow, red, black and golden are used in the production of dyes and special ink and in ceramics. The metal, as a structural material, is used in fast atomic reactors.

Gallium

When Mendeleev drew up his Periodic Table of elements in March 1869, in the fifth row of the third group, he left a blank space for an element which was not discovered till then. He called the new element eka-aluminium. Mendeleev held firm belief in the Periodic Law he proposed and on the basis of this he was was able to predict the existence and many of the properties of the then unknown element. In 1875, a French chemist Lacoq de Boisbaudran discovered a new element from zinc blende and he gave it the name gallium in honour of his country (*Gallia* is the Latin name for France). The properties of gallium and Mendeleev's theoretical eka-aluminium were surprisingly identical, except for the density. When Mendeleev heard about the discovery, he knew that this was his eka-aluminium. He had predicted its density to be 6 gm/cm^3 while the French chemist reported it as 4.7 gm/cm^3. Mendeleev was so confident and sure about his value that he asked the French chemist to repeat the experiment which he did and found to his consternation that the value was close to 6 gm/cm^3, as predicted by Mendeleev.

Gallium is rare because it is only found in traces in minerals of aluminium, iron or zinc. Gallium is also found in coal; 1 tonne contains 5 gm of gallium. However, the main sources of gallium are the waste products of the aluminium industry. It is a precious metal with uncommon properties. The melting point of this silvery, soft metal is 29.8°C. If the solid metal is held on the palm, it would melt by the very warmth of the hand.

Gallium remains a liquid over a very long range of temperatures—from 29.6°C to 2230°C . It is, therefore, used in high-temperature thermometers and is superior to mercury. Gallium thermometers can be used for temperatures of 1000°C and above (Fig. 31).

Gallium coated mirrors reflect light better than silver and are not discoloured at high temperatures. When used

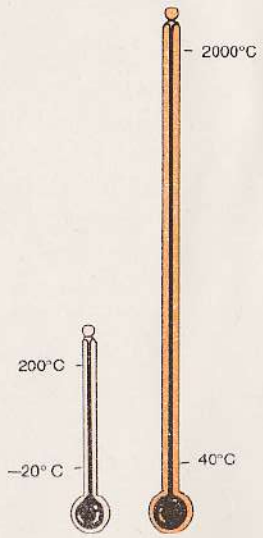


Fig. 31 : A gallium thermometer has a high temperature range.

in place of mercury in discharge lamps, gallium gives out stronger ultraviolet rays. Gallium oxide is used for the production of special glasses with high refractive index. These glasses transmit infrared rays better.

The most promising use of gallium is in semiconductors. Gallium, when alloyed with arsenic, antimony and phosphorus finds use as semiconductors. They also find use in solar batteries and transistors. Gallium arsenide is a semiconductor which can convert electricity directly into light and is used to make tiny lasers.

Today gallium compounds find use in computers, radars, solar batteries and in semiconductor devices for rocket-borne equipment, laser and also as catalysts in organic chemistry. Gallium is also tipped to be an ideal material for detecting low-energy neutrinos—neutral, massless particles—that are supposed to be produced in the core of the sun. Such an experiment might help shed light on one of the major problems of modern astrophysics.

Germanium

Germanium was one of the missing elements in Group IV of the Mendeleev's Periodic Table and he named it eka-silicon because of its position in-between silicon and tin. The German chemist C. Winkler reported the existence of this new element in argyrodite ore in 1866. Commercial recovery of germanium has been mainly achieved from

zinc and zinc-copper-lead ores, germanite and fly ash from coals.

Germanium is a metalloid, with properties between those of a true metal and a non-metal. It also belongs to the class of materials known as semiconductors and plays an important role in the electronics industry. High-purity germanium doped with arsenic or gallium is used for making transistors (Fig. 32) and diodes. Improvements in semiconducting devices have led to large-scale miniaturisation and improvements in electronic entertainment and communication equipment. Germanium also finds use in photoelectric cells, and as a phosphor in fluorescent lamps.

Germanium-containing glass is transparent to infrared radiation. This property is utilised in making lenses and prisms for infrared spectroscope and other optical instruments.

Fig. 32 : Germanium was used for making this first transistor.

Zirconium

Zirconium is known as a 'cinderella' metal because it is highly resistant to heat corrosion and radiation, yet highly malleable and ductile. It is a promising structural material used in atomic reactors as fuel cladding (Fig. 33). It also finds use in the construction of combustion chambers of jet engines and rockets because it can withstand high temperatures.

The element is found mostly as the mineral zircon in beach sands of Australia, Brazil and India. Production of the pure metal is difficult and poses problems. Zirconium was extracted in the free state for the first time by the Swedish chemist Jons Jacob Brezelius, in 1824 (Fig. 34). Obtaining the pure metal was, however, difficult because the metal was always accompanied by the element hafnium. The two metals have similarity in properties though

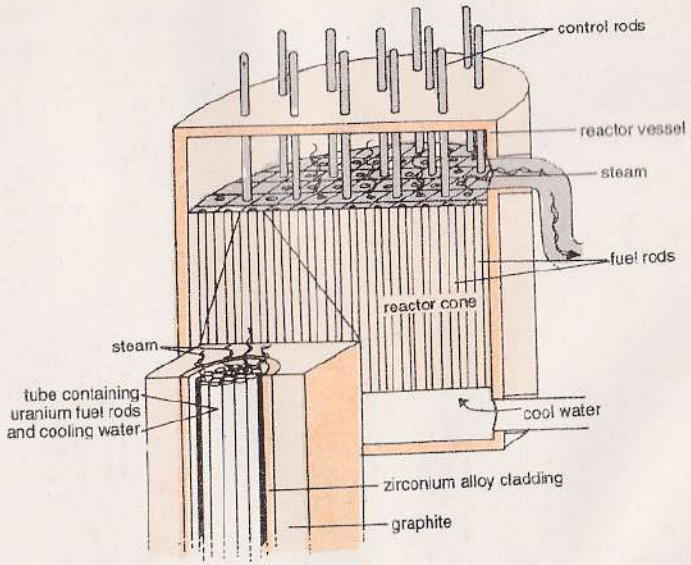


Fig. 33 : Zirconium is used as fuel cladding in an atomic reactor.

Fig. 34 : Jons Jacob Brezelius.

they have significant differences. Zirconium of highest purity is transparent to neutrons, while hafnium greedily absorbs them. Even a trace (0.0002 per cent) of hafnium reduces the transparency of zirconium almost six-and-a-half times. Because of its high transparency to neutrons, zirconium is used as sheathing for uranium fuel rods. Some other metals like magnesium and aluminum are similar to zirconium in properties, but zirconium is superior because it can stand the high neutron flux and high temperatures of atomic reactors (melting point of zirconium is 1850°C).

Zirconium compounds serve as good catalysts and are used in the production of high octane engine fuel. Zirconium dioxide has a melting point of 2700°C and is a good refractory material. Its another interesting property is that it emits intense light when hot. Walter Nernst (Fig. 35) adopted this property for the preparation of incandescent lamps. The mantle of the common petromax lamps also make use of this property of zirconium dioxide. Zirconium

Fig. 35 : Walter Nernst.

is no longer a rare element and no longer is it a problem to isolate pure zirconium from its widely scattered ores.

Molybdenum

Molybdenum resembles steel in colour and has an unusually high melting point (2610°C). Centuries ago the molybdenum ore, molybdenite, was used for writing as graphite is used nowadays in lead pencil. The element was discovered in molybdenite ore in 1778 by Carl Scheele. It is a rare element being present in the earth's crust only to the extent of 0.0003 per cent. Molybdenum, like graphite, acts as a lubricant. Samurai swords from Japan are famous for their extraordinary sharpness. It is now proved that the steel used in the preparation of these swords contained molybdenum. Addition of molybdenum retards the grain growth and makes the steel fine grained and homogeneous. The sword thus made is brittle but has no risks of developing cracks due to stress. Gun barrels (Fig. 36), aircraft and

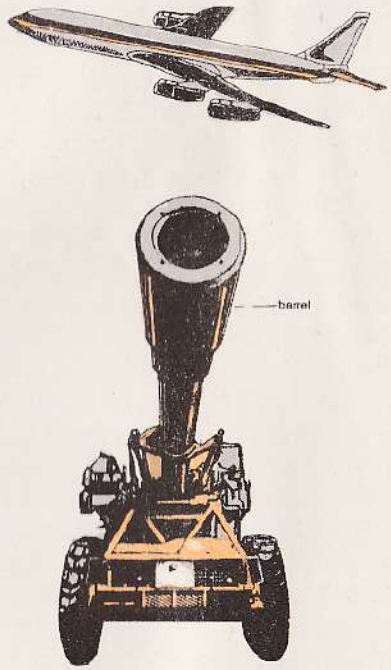


Fig. 36 : Molybdenum steel is used in the jet engine and the barrel of the Bofors gun.

automobile components, jet engines, missiles, and even the common razor blades use molybdenum steel. Addition of 20 per cent of molybdenum to steel makes it 'strong' and prevents it from cracking at temperatures of -200°C and at which welded steel containers are used to store liquid nitrogen.

Technetium

Mendeleev had predicted the presence of element 43; however, no experimental proof of its presence was available.

Possibly, element 43 was a radioactive element without a long half-life, and may have long disappeared from earth. It fact, element 43 was the first man-made element, and that is why it was called 'technetium', which means 'artificial'. During the summer of 1936, the Italian physicists Emilio Segre (Fig. 37) and C.Perrier went to Berkeley, USA to visit the 37-inch cyclotron where they irradiated molybdenum plates with powerful beams of accelerated deuterons. Traces of the new radioactive element were found in the irradiated molybdenum.

The most stable isotope, technetium-99 can be produced by bombarding molybdenum with neutrons. Molybdenum has 42 protons in the nucleus and 56 neutrons. Addition of one neutron turns it into the radioactive isotope molybdenum-99, which on releasing a ß particle becomes technetium-99 isotope.

Technetium is also found in the fission product of uranium. Every kilogramme of uranium fission product contains a few grammes of technetium.

Technetium has the unique quality of combating

Fig. 37 : Emilio Segre.

corrosion. Technetium inhibits corrosion by making the metal surfaces passive. Treatment of steel with a dilute solution of technetium salts makes it corrosion resistant upto a temperature of 250°C. The element is also used widely as a radioactive tracer in medical diagnosis.

Rubidium

Rubidium was discovered in 1861 by two German scientists, the chemist Robert Bunsen and physicist Gustav Kirchoff (Fig. 38). Though the name originates from the precious stone ruby, the metal, silvery-white in colour, is unlike ruby, which is red. It is very soft and melts at 38.9°C. Being very active chemically, rubidium on contact with air, immediately ignites and burns up with a bright pinkish-purple flame. The metal reacts more violently with water—it dissociates water into hydrogen and oxygen which instantaneously flare up.

The highly reactive nature of rubidium is easily understandable from its atomic structure. It belongs to the alkali group of metals; its single electron in the outermost shell

Fig. 38 : Gustav Kirchoff.

being far away from the nucleus is easily transferred to electron-deficient atoms. The presence of rubidium-87 isotope is used as a measure of the age of rocks. The half-life of rubidium-87 is 48,000 million years. It is transformed extremely slowly to stable strontium-87. The ratio of the isotopes 84, 86 and 87 of strontium in any rock is always constant. The amount of excess of strontium-87 in any rock is due to the radioactive decay of rubidium-87. Thus the age of the rock can be calculated from the ratio of rubidium -87/strontium-87 in a specimen.

Strontium

Strontium is the least abundant of the alkaline earth metals. The main ores are celesite, $SrSo_4$, and strontianite, $SrCo_3$. The Scotsman, Thomas Hope, in 1790, first identified naturally occurring strontium from a sample unearthed in a lead mine in Strontian, Scotland. The element was named after the place of its discovery. The credit for isolating pure strontium goes to Sir Humphry Davy, who isolated it in 1808 (Fig. 39). Priests could frighten worshippers by

Fig. 39 : Humphry Davy.

rubbing this metal in their palms so as to produce a red glow. What they did was to keep small balls, containing a pressed mixture of coal, sulphur and strontium and Berthollet's salt which on friction would emit the red glow. The light was known as 'Bengal light'. This property of strontium compounds to produce red light is also used in fireworks (Plate X). It has other uses too. Earlier it was used in sugar refining though nowadays cheaper calcium is preferred. Strontium compounds are used in the manufacture of fireworks, coloured glasses and ceramics. In the electronics industry strontium finds use as a deoxidiser for cathodes of electron tubes.

The radioactive isotope strontium-90 is used in thermoelectric generators for use in artificial earth satellites, deep-water research apparatus, and for powering remotely situated equipments such as lighthouses, or weather monitoring stations.

Cadmium

Cadmium is a relatively rare metal in the earth's crust. It is found mostly associated with the ores of other elements, especially of zinc and copper. The only ore of cadmium found in nature is the sulphide mineral, greenockite.

Cadmium was discovered in 1817 by the German chemist Friedrich Strohmeyer from zinc carbonate. It was named after the Greek word *kadmeia* for zinc carbonate. Cadmium is a soft, bluish-white metal, similar in many ways to zinc. It is widely used in electroplating delicate parts of iron and steel used in electronics industry. Metallic cadmiun, because of its neutron absorbing capacity, is used in nuclear reactors as control rods.

Cadmium-nickel (Cd-Ni) alloy has good anti-friction characteristics (99 per cent +1 per cent). Nickel used in bearings for automobiles, aircraft and marine engines, is given a coating of cadmium electrolytically. Vital parts in aircraft and ships are coated with cadmium as a protection against corrosion. Cadmium in the form of nickel-cadmium

storage cells (Plate XI) are used in spaceships, submarines, motor vehicles and radio sets. These cells have longer life and higher reliability than lead-acid batteries.

Rare Earth Elements

Rare earth elements or lanthanides comprise fifteen elements ranging between lanthanum, 57 and lutetium, 71. The rare earth elements were so called because they resembled substances like lime and magnesia which were once known as 'earths'. All these elements have almost similar chemical and physical properties. Therefore it is difficult to separate them from complex mineral mixtures in which they occur. During the Second World War, in the course of the Manhattan project carried out in USA, ion-exchange resins were adopted to separate the rare earth elements. Since the rare earth elements are no longer considered rare, they are better known as 'lanthanides' (Fig. 40). Some of the elements of this series and their compounds are very useful for space technology and in production of drugs. The alloys of aluminum and cerium are used in making pistons of aircraft engines. Nowadays lanthanides are used on a large scale in chemical industries as catalysts.

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
138.90	140.12	140.90	144.24	(145)	150.36	151.96	157.25	158.92	162.50	164.93	167.26	168.93	173.04	174.96
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
227.02	232.03	231.03	238.02	237.04	(244)	(243)	(247)	(247)	(251)	(254)	(257)	(258)	(255)	(260)

Fig. 40 : The lanthanides or the rare earth elements in the Periodic Table.

Lanthanides find wide applications in ceramics—neodymium and praseodymium oxides are used as colouring agents for glass; cerium oxide is used in enamels. Most of the lanthanides are good neutron absorbers and find use in nuclear technology. Samarium and europium are used in special alloys for making nuclear reactor parts. The ferromagnetic alloy of samarium with cobalt is used to produce permanent magnets, five times stronger than any other material.

5

THE RADIOACTIVE ELEMENTS

Elements heavier than bismuth are radioactive and are constantly disintegrating—emitting α β or γ rays. Eventually these radioactive elements—polonium, astatine, radon, francium, radium, actinium, thorium, protactinium and uranium—would disappear at some date in the distant future.

Polonium is a radioactive metal and is produced by the radioactive decay of minerals containing uranium and thorium. It was discovered in 1898 by Pierre and Marie Curie (Fig. 41). An isotope of polonium is used as a source of heat for generation of thermoelectric power in satellites.

Astatine is a halogen, discovered in 1940 by Emilio Segre, K.R. Mackenzie and Dale R. Corson.

Fig. 41 : Pierre and Marie Curie.

The last element of the sixth period of the Periodic Table is radon which is also the last element of the inert gas series. Radon is a radioactive, heavy gas produced by the radioactive decay of radium in the earth's crust. It is released by the soil and rocks. It is used for treating tumours, but if inhaled in large quantities, it can cause cancer.

Francium is the first element of the seventh period and radium, the second element. After radium, elements from actinium to lawrencium are known as actinides. If we look at the Periodic Table, we find that closely related elements starting with lanthanum and ending at lutetium in the sixth period are grouped together and known as 'lanthanides' or 'rare earths'. The existence of these closely related elements can be explained on the basis of the electronic structure of atoms. All these fifteen elements have almost identical physical and chemical properties. The actinides are radioactive but uranium is the last element available in trace quantities in the earth's crust in the form of an ore. The elements after uranium, starting from neptunium are prepared synthetically in the laboratory.

Francium

Of the gaps in Mendeleev's Periodic Table, three were filled by 1886. Gallium was discovered in 1875, scandium in 1879 and germanium in 1886. He had also kept an empty square below caesium, naming the unknown element eka-caesium. He had said that this would be the last element in alkali metal series.

The unknown element was discovered in 1913 by the British chemist Cranston who detected it in the radiation coming out of beta-active actinium-227. Thus the new element which is also radioactive must have been formed in a process of nuclear disintegration. However, the findings of Cranston were not accepted because the radiation showing the presence of atomic number 87 was very weak. Several attempts were made to obtain a clear proof but all

proved unsuccessful. Finally Marguerite Perey, a student of Marie Curie, succeeded in obtaining it. The modern method of producing francium is by irradiating a few microns-thick gold foil with accelerated ions of neon, but only a few thousand atoms can be produced at a time.

The half-life of the francium isotope is only 22 minutes. Obviously there was no possibility of its remaining in the earth's crust. Despite these observations, however, atoms of francium do exist in minute quantities. In 6×10^{23} kg of terrestrial material, the amount of francium would be a mere 500 gm.

Despite its being so rare, scientists are interested in francium for its unique property of accumulating in cancerous tissues in the initial stage of malignancy. Early diagnosis of cancer can therefore be made from the presence of francium. What a boon it would be for humanity if cancer could be detected in the initial stages!

Radium

Radium is a very rare radioactive metal. One tonne of the

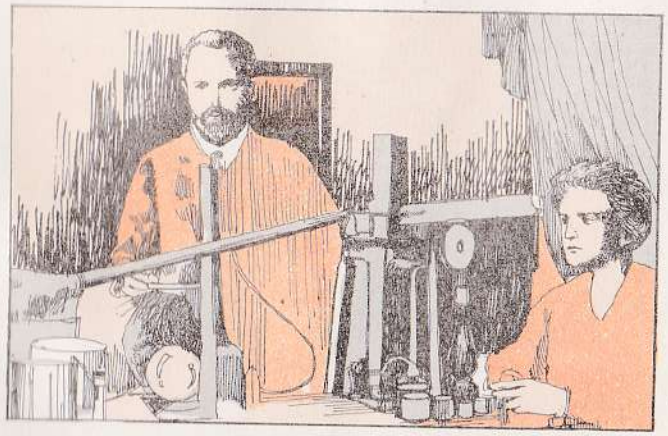


Fig. 42 : The Curies in their laboratory.

mineral pitchblende contains only a fraction of a gramme of pure radium. First isolated from pitchblende in 1898 by Marie and Pierre Curie (Fig. 42), radium is one of the most powerful natural sources of radioactivity. It is used chiefly as a source of radiation in medical treatment of cancers and in the industry for radiography (Plate XII). When combined with beryllium it can be used as a source of neutrons.

Uranium

Uranium was discovered in 1789 by the German chemist M.H.Klaproth in pitchblende. It was named after the planet Uranus by Klaproth. Pure metallic uranium was first isolated by Peligot in 1841. The industrial and scientific world, however, was indifferent to this heavy and soft metal. For practically 150 years uranium was of no

Fig. 43 : Henri Becquerel.

industrial significance.

Then, in 1896 the French chemist Henri Becquerel (Fig. 43) made a startling discovery—that of the phenomenon

of radioactivity, i.e. spontaneous emission of radiations by certain heavy elements including uranium. Becquerel found that the radiations emanating from uranium salts could affect a photographic plate just as light does.

It was, however, not until 1939 when nuclear fission was discovered that the real worth of uranium was recognised. Of the naturallly occurring uranium only the isotope uranium-235, which makes up just 0.7 per cent of natural uranium, is fissile. Uranium on bombardment with neutrons produced fragments which had atomic numbers almost half that of uranium. In the process of fission, two small nuclei were produced, the total mass of which was less than that of uranium. It was this small missing mass that turned into energy according to Einstein's famous equation $E=mc^2$, where m is the missing mass, c the velocity of light, and E the energy produced. As c is very large, the value of E also tends to be very large.

The demonstration of the tremendous energy hidden within the atom of uranium came in the form of the atom bomb dropped over the Japanese city of Hiroshima in August 1945 (Plate XIII). Although never used as a weapon again, since the end of the Second World War, stockpiling of atomic weapons still continues in many countries.

Uranium is today widely used as a fuel in nuclear reactors for generating electricity (Plate XIV). It is also used in smaller reactors to produce radioisotopes which are used in medicine, agriculture and industry.

6

MAN-MADE ELEMENTS

By 1920 only four elements with atomic numbers of 43, 81, 85 and 87 remained undiscovered between hydrogen and uranium. In the next ten years, before 1930, all the four were discovered. None of these elements was present in nature in detectable amounts. All four were prepared synthetically. The concentration of these elements synthesised in laboratory was, however, extremely small. In some cases it could be prepared only as a few atoms. Knowing their presence and confirming their existence required great skill and patience of the scientists.

The presence of element 101 was noted in the laboratory of Nobel laureate Glenn T. Seaborg (Fig. 44) at the

Fig. 44 : Glenn T. Seaborg.

University of California, in Berkeley, USA when only one or two atoms of the element were detected. It was named mendelevium after the father of the Periodic Table.

The key factor in the discovery of transuranic elements has been their position in the Periodic Table. Prior to the discovery of transuranic elements, the relationship of the naturally occurring elements—thorium, 90, protactinic, 91 and uranium, 92 in the Periodic Table was not clearly understood. Recognition of the fact that transuranic elements represented a whole new family of actinide elements, analogous to the lanthanide series of elements, permitted the discoverers to predict the chemical properties of the unknown transuranic elements.

The first scientific attempts to prepare elements beyond uranium and to explore the transuranic area were made by Enrico Fermi (Fig. 45), Emilio Segre and co-workers in Rome in 1934, shortly after the existence of neutron was discovered.

The discovery of neptunium is interesting. E.M. McMillan (Fig. 46), working at the University of California

Fig. 45 : Enrico Fermi.

Fig. 46 : E.M. McMillan.

in Berkeley, in 1940 was performing experiments on measuring the energies of two main recoiling fragments from the neutron-induced fission of uranium. In the course of his studies he found that there was another radioactive product of the reaction—one that did not recoil sufficiently to escape from the uranium undergoing fission, as did the fission products. He suspected that this was a product formed by neutron capture in the abundant, relatively non-fissionable isotope of uranium-238. He was able to show on the basis of his chemical work that the product was an isotope of element 93 formed by neutron capture and ß-decay. Element 93 was given the name neptunium because it was beyond uranium, just as the planet Neptune is beyond Uranus.

The next transuranic element 94 was synthesised by bombarding uranium with deuterons in late 1940 by E.M. McMillan and his co-workers. They succeeded in preparing a new isotope, neptunium-238, which decayed to an isotope of the element 94. The name 'plutonium' was given because Pluto is the next planet beyond Neptune.

Plutonium (Plate XV) was soon found to be a useful nuclear fuel like uranium-235. It is therefore the only synthetic element yet made in kilogramme quantities.

Elements 95 and 96 were discovered during 1944 and early 1945. Element 95 was named americium and element 96, curium in honour of Marie Curie and Pierre Curie. Element 97 was discovered at Berkeley in 1950 and was designated as berkelium. Element 96 was given the name calilfornium.

The discovery of elements 99 and 100, the next two elements, represented an outstanding example of unexpected and incidental discovery. These two were discovered in the debris of the thermonuclear explosion of November 1952 carried out in the Pacific Ocean by the USA. The material blown out into the upper atmosphere was examined by collecting it on a filter paper by aeroplanes passing through the explosion cloud. Elements 99 and 100 were positively identified. Element 99 was named einsteinium in honour of Albert Einstein (Fig. 47), and element 100, fermium in honour of the father the Atomic Age, Enrico Fermi.

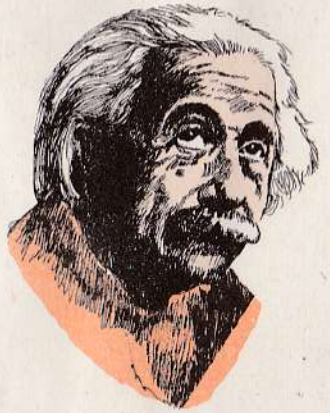


Fig. 47 : Albert Einstein.

Elements Beyond Mendelevium

All the isotopes of elements below mendelevium were discovered and their radioactive decay was understood fairly well by 1960. Their half-lives seemed to become shorter and shorter with increasing atomic number. Evidently, for elements 104 and 105, their isotopes will have such a short half-life that they will exist barely long enough to enable chemical identification to be made. We will, therefore, have to study them through their decay and chemical properties. Careful measurements show that we can go upto element 118.

Transuranic Elements and their Half-Lives

At. No	*Name*	*Symbol (isotope)*	*Half-life*
93	Neptunium	Np (239)	2.35 days
94	Plutonium	Pu (238)	86.4 days
95	Americium	Am (241)	458 years
96	Curium	Cm (242)	162.5 days
97	Berkelium	Bk (243)	4.5 hours
98	Californium	Cf (245)	44 minutes
99	Einsteinium	Es (253)	20 days
100	Fermium	Fm (255)	22 hours
101	Mendelevium	Md (256)	1.5 hours
102	Nobelium	No (254)	3 seconds
103	Lawrencium	Lw (257)	8 seconds
104	Un-nil quadium	Unq (-)	—
105	Un-nil-pentium	Unp (-)	—
106	Un-nil-hexium	Unh (-)	—

List of the Elements
(Latin names are mentioned, wherever necessary)

Atomic No.	*Element*	*Symbol*	*Latin Name*
1	*2*	*3*	*4*
1.	Hydrogen	H	
2.	Helium	He	
3.	Lithium	Li	
4.	Beryllium	Be	
5.	Boron	B	
6.	Carbon	C	
7.	Nitrogen	N	
8.	Oxygen	O	
9.	Fluorine	F	
10.	Neon	Ne	
11.	Sodium	Na	Natrium
12.	Magnesium	Mg	
13.	Aluminium	Al	
14.	Silicon	Si	
15.	Phosphorus	P	
16.	Sulphur	S	
17.	Chlorine	Cl	
18.	Argon	Ar	
19.	Potassium	K	Kalium
20.	Calcium	Ca	
21.	Scandium	Sc	
22.	Titanium	Ti	
23.	Vanadium	V	
24.	Chromium	Cr	
25.	Manganese	Mn	
26.	Iron	Fe	Ferrum
27.	Cobalt	Co	
28.	Nickel	Ni	
29.	Copper	Cu	Cuprum
30.	Zinc	Zn	
31.	Gallium	Ga	
32.	Germanium	Ge	

1	2	3	4
33.	Arsenic	As	
34.	Selenium	Se	
35.	Bromine	Br	
36.	Krypton	K4r	
37.	Rubidium	Rb	
38.	Strontium	Sr	
39.	Yttrium	Y	
40.	Zirconium	Zr	
41.	Niobium	Nb	
42.	Molybdenum	Mo	
43.	Technetium	Tc	
44.	Ruthenium	Ru	
45.	Rhodium	Rh	
46.	Palladium	Pd	
47.	Silver	Ag	Argentum
48.	Cadmium	Cd	
49.	Indium	In	
50.	Tin	Sn	Stannum
51.	Antimony	Sb	Stibium
52.	Tellurium	Te	
53.	Iodine	I	
54.	Xenon	Xe	
55.	Caesium	Cs	
56.	Barium	Ba	
57.	Lanthanum	La	
58.	Cerium	Ce	
59.	Praseodymium	Pr	
60.	Neodymium	Nd	
61.	Promethium	Pm	
62.	Samarium	Sm	
63.	Europium	Eu	
64.	Gadolinium	Gd	
65.	Terbium	Tb	
66.	Dysprosium	Dy	
67.	Holmium	Ho	
68.	Erbium	Er	

1	2	3	4
69.	Thulium	Tm	
70.	Ytterbium	Yb	
71.	Lutetium	Lu	
72.	Hafnium	Hf	
73.	Tantalum	Ta	
74.	Tungsten	W	Wolfram
75.	Rhenium	Re	
76.	Osmium	Os	
77.	Iridium	Ir	
78.	Platinum	Pt	
79.	Gold	Au	Aurum
80.	Mercury	Hg	Hydrargyrum
81.	Thallium	Tl	
82.	Lead	Pb	Plumbum
83.	Bismuth	Bi	
84.	Polonium	Po	
85.	Astatine	At	
86.	Radon	Rn	
87.	Francium	Fr	
88.	Radium	Ra	
89.	Actinium	Ac	
90.	Thorium	Th	
91.	Protactinium	Pa	
92.	Uranium	U	
93.	Neptunium	Np	
94.	Plutonium	Pu	
95.	Americium	Am	
96.	Curium	Cm	
97.	Berkelium	Bk	
98.	Californium	Cf	
99.	Einsteinium	Es	
100.	Fermium	Fm	
101.	Mendelevium	Md	
102.	Nobelium	No	
103.	Lawrencium	Lw	

Nomenclature of Elements having Atomic Number more than 100 (approved by IUPAC, 1977)

1	2	3	4
101	Un-nil-unium	Unu	
102	Un-nil-bium	Unb	
103	Un-nil-trium	Unt	
104	Un-nil-quadium	Unq	
105	Un-nil-pentium	Unp	
106	Un-nil-hexium	Unh	
107	Un-nil-septium	Uns	
108	Un-nil-octium	Uno	
109	Un-nil-ennium	Une	
110	Un-un-nilium	Uun	

Note: The name is derived directly from the atomic number of the element using the following numerical roots:

0	1	2	3	4	5	6	7	8	9
nil	un	bi	tri	quad	pent	hex	sept	oct	enn

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